



Environmental Effects of Dredging Technical Notes



INTERIM PROCEDURES FOR ESTIMATING MIXING ZONES FOR EFFLUENT FROM DREDGED MATERIAL DISPOSAL SITES (Single-Point Discharge)

PURPOSE AND SCOPE: This technical note presents a simple analytical method for evaluating the size of mixing zones for effluents from confined dredged material disposal areas. The method involves a simplistic two-dimensional calculation based on dispersion principles. Discussions of the applicability and limitations of the technique and a stepwise procedure for performing the required calculations are presented. Recommendations for using computer-based approaches for more complex conditions are also discussed.

BACKGROUND: Contaminated dredged material that is unsuitable for disposal in open water is normally placed in confined upland disposal areas. The quality of effluent discharged from these sites is an environmental concern and is regulated as a discharge under Section 404 of the Clean Water Act. Further, water quality certification may be required from state regulatory agencies, and effluent standards may be set as a condition of the certification. This technical note addresses one aspect of the required estimation techniques: the evaluation of mixing-zone sizes in receiving waters for the effluent from confined disposal sites.

Whenever contaminant concentrations in an effluent at the point of discharge from a confined disposal site are above receiving water quality standards, there will be some limited initial mixing zone (or zone of dilution) in the vicinity of the discharge point where receiving water quality standards may be exceeded. The size of this mixing zone depends on a number of factors including the contaminant concentrations in the effluent, the applicable water quality standards, effluent density and flow rate, receiving water flow rate and turbulence, and the geometry of the discharge structure and the receiving water boundaries. Since the maximum allowable mixing zone specified by regulatory agencies is usually on the order of hundreds of meters, the evaluation of mixing-zone sizes must necessarily be based on calculation of near-field dilution and dispersion processes.

Mixing-zone sizes can be best determined from field studies at the proposed discharge site using dye plumes to measure dispersion. However, this method is time-consuming and expensive; therefore, a technique utilizing calculations based on theoretical and empirical studies of effluent dispersion is desirable. There are a variety of possible estimation techniques for most real mixing-zone problems, but any choice of a suitable technique involves some tradeoffs. The available techniques may be thought of as ranging from sophisticated computer models, which are sometimes capable of very accurate

19950327101

US Army Engineer Waterways Experiment Station, Environmental Laboratory
PO Box 631, Vicksburg, Mississippi 39180-0631

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unrestricted

DTIC GEN 04-5

predictions, to simple approximations that yield order-of-magnitude estimates. The most sophisticated models will not usually run on a microcomputer, and they may require a considerable amount of measured data and manpower for calibration of the model to a single site. By contrast, the simplest of approximations may be made on the basis of several simplifying assumptions and hand calculations.

An example of a simple approach to mixing-zone size estimation was proposed for discharges of dredged material into navigable waters (Environmental Effects Laboratory 1976). This report presented a simplified method to calculate mixing-zone sizes for offshore dumping of dredged material. The method involved the use of some characteristic plume shapes and an estimate of the amount of the dispersion based on a wide range of experimental studies. Unfortunately this method can only be applied in the case of open-water disposal well away from boundaries and flow restrictions. The method is not applicable to mixing zones for effluent from containment areas, which is generally discharged into relatively shallow water necessarily close to such boundaries as the river or estuary bottom and bank.

This technical note presents a similar type of simplified approach that is applicable to relatively shallow confined riverine water bodies. If the mixing-zone size as calculated using simple approximations is within mixing-zone guidelines specified by regulatory agencies, more precise calculations may not be necessary.

(Note: The mixing-zone calculations described in this technical note depend on a number of assumptions that are difficult to satisfy for estuaries and the tidally influenced portions of rivers. The difficulties are discussed after the presentation of the procedure to be used for a riverine environment.)

REGULATORY ASPECTS: The Federal regulations (Environmental Protection Agency 1980a) that apply to all discharges of dredged or fill material into waters of the United States are contained in pages 85336-85337 of the Federal Register, Volume 45. Since confined disposal area effluents are usually discharged into waters of the United States, nearly all containment area discharges fall under the jurisdiction of these regulations. In Part 230.3(m), the mixing-zone of a discharge is defined as "a limited volume of water serving as a zone of initial dilution in the immediate vicinity of a discharge point where receiving water quality may not meet quality standards or other requirements otherwise applicable to the receiving water." The guidelines recognize that it is not possible to set universal standards for the acceptable size of mixing zones since receiving water conditions vary so much from one location to another. The guidelines therefore instruct that, as part of the dredging permit process, the size of any proposed mixing zone should be estimated and submitted to the permitting authority. The permitting authority must then consider receiving water conditions at the proposed site and decide if the proposed mixing-zone size is acceptable.

Many state regulatory agencies may specify a limit to mixing-zone dimensions as a condition in granting the state water quality certification for a confined disposal operation. In this case the mixing zone necessary to meet applicable standards must be smaller than the specified limits.

Proposed amendments (Environmental Protection Agency 1980b) to the Section 404 regulations, given in pages 85360-85367 of the Federal Register, Volume 45, deal with the testing requirements for the specification of

dredged material disposal sites. If they are approved, they will replace Parts 230.60 and 230.61 in the current regulations. These proposed amendments give much more detailed guidance on how mixing-zone sizes should be estimated for permit applications. They recommend that effluent contaminant concentrations should be estimated by means of a modified elutriate test (Palermo 1986). There is also a general description of appropriate approaches to estimating mixing-zone size once the concentration of the most critical effluent pollutant has been estimated. The recommended approaches are as follows:

"(a) Mixing Zone Calculations. The perimeter of the mixing zone shall be defined by the applicable water quality standard of the contaminant requiring the greatest dilution volume or by 0.01 of the lowest 96-hour LC50 when a water column bioassay has been conducted.

(1) One of the following methods (provided in order of preference) shall be used to determine the volume and conformation of the zone required to achieve dilution and dispersal of contaminants to numerical limitations specified in Federal or State water quality standards or to 0.01 of the lowest 96-hour LC50, as indicated above.

(i) When field data on the proposed discharge are adequate to predict the initial dispersion and diffusion of the discharge plume, such data shall be used; or

(ii) When field data on the dispersion and diffusion of a discharge with similar characteristics are available, these data shall be used in conjunction with an appropriate mathematical model (acceptable to the permitting authority) to make the required determination; or

(iii) When the above methods are impractical, due to inadequate field data or the unavailability of an appropriate mathematical model, the zone of dilution and dispersion may be estimated by assuming particular geometrical shapes for the disposal plume."

The estimation techniques presented in this technical note would fall under class iii of the proposed amendments.

ACKNOWLEDGEMENTS: The author of this technical note is Dr. David F. MacIntyre, who was associated with the US Army Engineer Waterways Experiment Station (WES) Environmental Laboratory under an Intragovernmental Personnel Act agreement with the University of Florida. The technical approach on calculation of mixing zones was coordinated with Dr. Billy H. Johnson of the WES Hydraulics Laboratory.

ADDITIONAL INFORMATION OR QUESTIONS: Contact Dr. Michael R. Palermo (601) 634-3753 (FTS 542-3753), or the manager of the Environmental Effects of Dredging Programs, Dr. Robert M. Engler (601) 634-3624 (FTS 542-3624).

| | |
|--------------------|-------------------------------------|
| Accession For | |
| NTIS CRA&I | <input checked="" type="checkbox"/> |
| DTIC TAB | <input type="checkbox"/> |
| Unannounced | <input type="checkbox"/> |
| Justification | |
| <i>Not from SD</i> | |
| By _____ | |
| Distribution / | |
| Availability Codes | |
| Dist | Avail and/or Special |
| <i>A-1</i> | |

Analytical Method for Estimating Mixing Zones

The analytical solution technique for calculating mixing-zone size described in this section is based on theoretical and empirical relationships for dispersion as summarized by Fischer et al. (1979). Only equations for calculating mixing-zone size resulting from a single-point discharge are presented. Development of the specific equations used, additional equations for multiple points of discharge, and more detailed discussions of the solution techniques are presented by MacIntyre (in review).

A schematic illustrating a typical single-source effluent discharging into a receiving water body is shown in Figure 1. For such a condition, the mixing-zone length extends downstream and the body of the mixing zone remains close to the shoreline of the receiving water body.

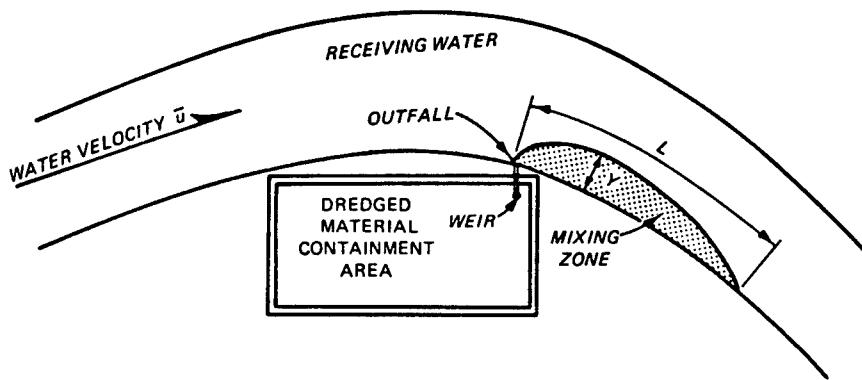


Figure 1. Schematic of a mixing zone for a single effluent source

Data requirements

The following data are required for evaluating mixing-zone sizes for confined disposal area effluents:

- a. Effluent concentrations at the point of discharge and receiving water background concentrations for all contaminants of concern.
- b. Water quality standards applicable at the limit of the allowable mixing zone for all contaminants of concern.
- c. Depth, cross-sectional area, and current velocity of the receiving water body during expected low flow conditions.
- d. Effluent volumetric flow rate.

Calculation procedure

The stepwise procedure for calculating mixing-zone sizes is summarized as follows:

- Step 1. Check that the assumptions on which the equations depend are reasonable for conditions at the proposed discharge site.
- Step 2. Use effluent, receiving water, and water quality standard concentrations of all contaminants of concern to identify the critical contaminant. The critical contaminant is the one that requires the greatest dilution, which will define the boundary of the mixing zone.
- Step 3. Use receiving-water depth and velocity data to calculate a lateral mixing coefficient. This coefficient is a measure of how rapidly the effluent is dispersed through the receiving water.
- Step 4. Calculate mixing-zone length.
- Step 5. Check assumptions that depend on mixing-zone length.
- Step 6. Calculate the maximum width of the mixing zone.

Step 1 - Assumptions. In order to apply the analytical solution described in this section, the following assumptions are required:

- a. No major change in cross-sectional shape, sharp bends, major inflows or outflows, or obstructions to flow exist in the receiving water body in proximity to the mixing zone.
- b. The receiving water body can be reasonably approximated by a shallow rectangular cross section.
- c. The confined disposal area effluent enters the receiving water as a point source at the bank with negligible horizontal momentum.
- d. Differences in density between the effluent and receiving water and in settling rates of suspended particles within the boundary of the mixing zone are negligible.
- e. The flow condition in the vicinity of the mixing zone can be approximated as a steady-state velocity flowing parallel to the bank of the receiving water.
- f. The major cause of dispersion in the receiving water body is the turbulence and shear flow associated with the horizontal water flow.
- g. The effluent plume is vertically well mixed, so that contaminant concentrations do not vary significantly with depth.
- h. The width of the effluent plume is small enough that its lateral dispersion is not restricted by the opposite bank of the receiving water body.

Step 2 - Identify critical contaminant. It is necessary to calculate the dilution required within the mixing zone in order to reach applicable water quality standards for all contaminants of concern. This requires an estimate of the effluent concentrations of regulated contaminants. The contaminant that requires the greatest amount of dilution will define the maximum boundary of the mixing zone.

Effluent from containment areas may contain chemical contaminants that are dissolved and/or adsorbed to suspended particles. The total effluent concentration of any contaminant consists of the sum of the concentrations of that contaminant in the dissolved and adsorbed states. This concentration should be estimated for each contaminant of concern by using a modified elutriate test. Procedures for use of the modified elutriate test and calculation of the required concentrations were published by Palermo (1986), with supplemental guidance on estimating the total suspended solids (TSS) concentration in the effluent. For each contaminant of concern, including TSS, the required dilution should be calculated as:

$$D = \frac{C_e - C_s}{C_s - C_b} \quad (1)$$

where

D = dilution factor required to dilute the contaminant of concern to the appropriate water quality standard C_s , vol/vol

C_e = concentration of contaminant of concern in the effluent water, mg/l^{-1}

C_s = receiving water quality standard for the contaminant of concern, mg/l^{-1}

C_b = background concentration of the contaminant of concern in the receiving water, mg/l^{-1}

The maximum boundary of the mixing zone will be defined as the isopleth (line of constant concentration) where the concentration of the most critical contaminant is reduced to the concentration specified by the appropriate water quality standard. It should be noted that if background concentrations exceed the water quality standard, the concept of a mixing zone is inapplicable.

Also, this approach for calculating required dilution is not applicable to turbidity (an optical property of water), which is reduced in a nonlinear fashion by dilution. A correlation curve for TSS versus turbidity (Earhardt

1984) should be used to define the TSS concentration corresponding to the water quality standard for turbidity. This TSS concentration can be used as a value for C_s and an appropriate TSS dilution calculated.

Step 3 - Estimate of lateral mixing coefficient.

Step 3.1. The depth of a simplified rectangular cross section for the receiving water body should be calculated as follows:

$$d = \frac{A}{W} \quad (2)$$

where

d = average depth of the receiving water body channel, m

A = cross-sectional area of the channel, m^2

W = surface width of the channel, m

Check to ensure that W is equal to or greater than 10 times the average depth d . If not, the estimate of a lateral mixing coefficient is likely to be inaccurate.

Step 3.2. Estimate the shear velocity by one of the following methods. In rivers where the mean channel slope is known, use:

$$u^* = \sqrt{gdS} \quad (3)$$

In rivers where the channel slope is not known, use:

$$u^* = 0.1 \bar{u} \quad (4)$$

where

u^* = shear velocity in receiving water, m/sec^{-1}

g = gravitational acceleration, $9.81 m/sec^{-2}$

d = average channel depth, m (equation 2)

S = slope of river bed (dimensionless)

\bar{u} = average of instantaneous velocities across the channel cross section, m/sec^{-1} .

If the flow rate of the receiving water is known, \bar{u} can be calculated as the flow rate divided by the channel cross-sectional area. If the receiving-water flow rate is not known, \bar{u} must be determined from velocity measurements taken at the proposed site. It should be noted that \bar{u}

should not be determined over a period of time during which velocity changes occur due to changes in the receiving-water flow rate.

Step 3.3. Estimate the lateral mixing coefficient by using one of the following equations.

In rivers:

$$E_t = 0.3 du^* \quad (5)$$

In estuaries:

$$E_t = 0.4 du^* \quad (6)$$

where

E_t = lateral mixing coefficient, m^2/sec^{-1}

d = average channel depth, m (equation 2)

u^* = shear velocity, m/sec^{-1} (equations 3 or 4)

The values of lateral mixing coefficient are derived from Fischer et al. (1979) and are based on experimental studies of dispersion in various rivers. Lateral mixing coefficients have been shown to vary widely from one location to another, and equations 5 and 6 give the lowest reasonable values so that estimates of mixing zone size will be conservative.

Step 4 - Estimate mixing-zone length. If the assumptions presented earlier are valid, the mixing zone will have a shape similar to the one shown in Figure 1. The length of the mixing zone (measured parallel to the bank) can be estimated as:

$$L = \left(\frac{1}{\pi E_t u} \right) \left[\frac{Q_e C_e}{(C_s - C_b)d} \right]^2 \quad (7)$$

where

L = mixing zone length, m

Q_e = effluent volumetric discharge rate, m^3/sec^{-1}

Step 5 - Check length-dependent assumptions.

Step 5.1. The flow in the water body near the mixing zone can be treated as a steady-state flow as long as:

$$L \leq \frac{\bar{u}T_c}{10} \quad (8)$$

where

L = predicted mixing zone length, m (Equation 7)

\bar{u} = cross-sectional average velocity (instantaneous or averaged over a few minutes), m/sec⁻¹

T_c = time taken for the observed value of \bar{u} to change by 10 percent, sec

Step 5.2. The lateral dispersion of the effluent plume will not be restricted by opposite bank of the receiving water body as long as:

$$W \geq \sqrt{\frac{8 E_t L}{\bar{u}}} \quad (9)$$

where W = surface width of receiving water channel, m.

Step 6 - Estimate maximum width of mixing zone. The maximum width of the mixing zone (measured perpendicular to the bank as shown in Figure 1) can be estimated as:

$$Y = \frac{0.484 Q_e C_e}{\bar{u}(C_s - C_b)d} \quad (10)$$

where Y = maximum width of the mixing zone, m.

Example mixing-zone problem

Following is a hypothetical mixing-zone problem designed to illustrate the use of the mixing-zone estimation equations. A proposed dredged material containment area is expected to discharge into a river 480 ft (146.3 m) wide. From a study of US Geological Survey stream gage records, it is anticipated that while effluent will be discharged, the lowest river flow will be about 7,600 ft³/sec (212.8 m³/sec) and that the river has a cross-sectional area of 4,000 ft² (371.6 m²) at this flow rate. The local bed slope of the river is known to be very variable due to sediment transport. The containment area is expected to have a peak discharge of 15 cfs. The only effluent contaminant that exceeds water quality standards will be cadmium, which is expected to have an effluent concentration of 3.5 µg/l. The background concentration of cadmium in the river is below the detection limit of 0.1 µg/l, and the applicable cadmium water quality standard is 0.25 µg/l. It has been specified that the maximum acceptable mixing-zone size is a 750-ft (228.6-m) radius centered on the effluent outfall. Is the size of the mixing zone likely to exceed this limit?

Step 1 - Assumptions. Since the purpose of this hypothetical problem is to demonstrate the use of the mixing-zone calculations, it has been defined so that all the assumptions on which the calculations depend are valid. Decisions on whether the assumptions are valid depend largely on the professional judgement of personnel familiar with the disposal site. More detailed guidance on which types of local conditions will satisfy the assumptions is given by MacIntyre (in review).

Step 2 - Identify critical contaminant. Cadmium is the only effluent contaminant that exceeds water quality standards. It is therefore unnecessary to use equation 1 to determine the critical contaminant, because cadmium is the only possibility.

Step 3 - Estimate lateral mixing coefficient.

Step 3.1. From the problem statement,

$$A = 4,000 \text{ ft}^2 (371.6 \text{ m}^2)$$

$$W = 480 \text{ ft (146.3 m)}$$

Calculate depth from equation 2:

$$d = \frac{A}{W}$$

$$d = \frac{371.6 \text{ m}^2}{146.3 \text{ m}} = 2.54 \text{ m}$$

Check that $W \geq 10 d$. It is.

Step 3.2. Since the local bed slope is known to vary due to sediment transport, the shear velocity should be estimated from the mean velocity. Calculate the mean velocity by dividing the river flow of $7,600 \text{ ft}^3/\text{sec}$ ($212.8 \text{ m}^3/\text{sec}$) by the cross-sectional area of $4,000 \text{ ft}^2 (371.6 \text{ m}^2)$.

$$\bar{u} = \frac{7,600 \text{ cfs}}{4,000 \text{ ft}^2} = 1.90 \text{ ft/sec}^{-1} (0.579 \text{ m/sec}^{-1})$$

From equation 4:

$$u^* = 0.1 \bar{u}$$

$$u^* = 0.1(0.579 \text{ m/sec}^{-1}) = 0.0579 \text{ m/sec}^{-1}$$

Step 3.3. In rivers, the lateral mixing coefficient should be estimated from equation 5:

$$E_t = 0.3 d \bar{u}^*$$

$$E_t = 0.3(2.54 \text{ m})(0.0579 \text{ m/sec}^{-1})$$

$$E_t = 0.0441 \text{ m}^2/\text{sec}^{-1}$$

Step 4 - Estimate mixing-zone length. From the problem statement,

$$Q_e = 15 \text{ cfs } (0.425 \text{ m}^3/\text{sec}^{-1})$$

$$C_e = 3.5 \mu\text{g/l}^{-1} (3.5 \times 10^{-3} \text{ mg/l}^{-1})$$

$$C_s = 0.25 \mu\text{g/l}^{-1} (2.5 \times 10^{-4} \text{ mg/l}^{-1})$$

$$C_b < 0.1 \mu\text{g/l}^{-1} (1.0 \times 10^{-4} \text{ mg/l}^{-1})$$

In order to be conservative, it would be wise to assume that the background concentration is only just under the detection limit, rather than zero. Therefore use:

$$C_b = 1.0 \times 10^{-4} \text{ mg/l}^{-1}$$

Calculate mixing-zone length from equation 7:

$$L = \left(\frac{1}{\pi E_t \bar{u}} \right) \left[\frac{Q_e C_e}{(C_s - C_b) d} \right]^2$$

$$L = \left[\frac{1}{\pi (0.0441 \text{ m}^2/\text{sec}^{-1}) (0.579 \text{ m/sec}^{-1})} \right]$$

$$\left\{ \frac{(0.425 \text{ m}^2/\text{sec}) (3.5 \times 10^{-3} \text{ mg/l}^{-1})}{[(2.5 - 1.0) \times 10^{-4} \text{ mg/l}^{-1}] (2.54 \text{ m})} \right\}$$

$$L = 190 \text{ m (623 ft)}$$

Step 5 - Check length-dependent assumptions.

Step 5.1. Equation 8 requires that:

$$L \leq \frac{\bar{u}T_c}{10}$$

therefore

$$T_c \geq \frac{10L}{\bar{u}}$$

$$T_c \geq \frac{10(190 \text{ m})}{0.579 \text{ m/sec}^{-1}}$$

$$T_c \geq 3,280 \text{ sec (55 min)}$$

This is acceptable since the river flow will certainly not change by 10 percent in less than 1 hour.

Step 5.2. Equation 9 requires that:

$$W \geq \sqrt{\frac{8E_t L}{\bar{u}}}$$

$$W \geq \sqrt{\frac{8(0.0441 \text{ m}^2/\text{sec}^{-1})(190 \text{ m})}{(0.579 \text{ m/sec}^{-1})}}$$

$$W \geq 10.8 \text{ m}$$

This condition is amply satisfied since W equals 146 m.

Step 6 - Estimate maximum width of mixing zone. Estimate the maximum mixing zone width from equation 10:

$$Y = \frac{0.484 Q_e C_e}{\bar{u}(C_s - C_b)d}$$

$$Y = \frac{0.484 (0.425 \text{ m}^3/\text{sec}^{-1})(3.5 \times 10^{-3} \text{ mg/l}^{-1})}{0.579 \text{ m/sec}^{-1} [(2.5 - 1.0) \times 10^{-4} \text{ mg/l}^{-1}](2.54 \text{ m})}$$

$$Y = 3.3 \text{ m (10.7 ft)}$$

Since the mixing zone is predicted to have a length of 623 ft (190 m) and a maximum width of 10.7 ft (3.3 m), it is within the allowable limits of 750 ft (228.6 m) from the effluent outfall.

Multiple sources

A similar computational sequence has been devised for the case of multiple sources or points of discharge. This condition would exist if multiple weirs discharge simultaneously to the receiving water body. Detailed procedures for this case are given in MacIntyre (in review).

Tidal rivers and estuaries

The mixing-zone equations presented earlier depend on a number of assumptions that are more difficult to satisfy in estuaries and the tidally influenced portions of rivers. These difficulties are reviewed briefly below.

The assumption that velocities in the water body near the mixing zone can be represented by a single mean velocity parallel to the bank is usually a reasonable one in the tidally influenced portion of a river. However, it is not always acceptable in estuaries. Typically the downstream section of an estuary exhibits horizontal circulation patterns, so that the horizontal water velocity and direction vary with distance parallel to the bank, distance perpendicular to the bank, and time. Under these conditions, water near the mixing zone may not always travel parallel to the bank. Therefore, the simple mixing-zone equations presented in this technical note may not be applicable to the wide, open low-velocity sections of estuaries.

Also, the mixing-zone equations are not theoretically applicable as the mean velocity tends to zero. This is because the equations are dependent upon the process of advection, which does not exist in the absence of a flow velocity, and also because the primary source of dispersion is assumed to be the turbulence caused by the horizontal movement of water. However, in a real water body, as the velocity tends to zero, the primary sources of turbulence and dispersion are the wind and waves.

The rate of change of water velocity due to tidal effects can also cause problems. Step 5 presents an equation for steady-state flow conditions: the time taken for material to travel the length of the mixing zone should be an order of magnitude smaller than the time taken for a 10-percent change in the mean water velocity. It may be possible to satisfy this condition in the tidally influenced portion of a river, but it will probably not be possible to do so in most estuaries during a significant portion of the tidal cycle.

Methodologies for estimating the overall mixing-zone size under these conditions by superimposing a series of instantaneous mixing zones are discussed in MacIntyre (in review).

Another potential difficulty in estuaries is the phenomenon of stratification. Estuaries with low water velocities sometimes have a layer of relatively fresh water near the surface with a much more saline denser layer of water near the bottom and with quite a distinct interface between the two layers. The abrupt change of density at the interface tends to inhibit vertical mixing through the entire depth of the water column. Fischer et al. (1979) stated that the equation given for the lateral mixing coefficient in estuaries was derived from studies in the unstratified portions of estuaries. The methods of estimating mixing-zone size that are presented in this report are therefore not recommended for use under conditions in which strong vertical stratification is present in the immediate vicinity of the mixing zone.

Computer Modeling of Mixing Zones

The equations presented earlier were derived from a simplistic approach to the problem of estimating mixing-zone size that made it possible to use a combination of empirical and analytical solutions. The simplifications that make the calculations easily manageable are somewhat restrictive, and a more advanced set of similar empirical and analytical solutions could be used to estimate mixing-zone sizes under more complex conditions. The more advanced analytical solutions involve many more computations, and for this reason they are more easily dealt with by use of a computer. The simplicity and limited data requirements of analytical solutions make them an attractive tool. However, analytical solutions cannot be used for receiving water where there are complex hydrodynamic conditions, nor can they be applied under dynamic (unsteady) flow conditions. Where these conditions exist, a numerical model must be used, and numerical dispersion models are not susceptible to hand calculation. In addition to requiring a computer solution technique, numerical models generally require a much more detailed set of input data, and the collection of such data can be expensive.

Vanderbilt University (Saenz and Parker 1984) conducted a study of available computer models suitable for modeling mixing zones. Their report did not identify any models that were suitable for a broad range of

mixing-zone conditions. An updated literature review by MacIntyre (in review) came to the same broad conclusion: there are no readily available models suitable for modeling the first few hundred metres downstream from the discharge point. This is because the overwhelming majority of computer models are concerned with far-field solutions where concentrations can be adequately described by a two-dimensional or a one-dimensional model and the initial characteristics of the discharge are relatively unimportant. These models are generally inadequate in the immediate vicinity of a discharge, where a three-dimensional description of concentrations is often necessary and where the initial characteristics of the discharge can be highly significant. Within the first few hundred metres of the discharge, there are several different processes that may be significant, so a general model must be able to estimate each of the processes (for example, momentum, buoyancy, dispersion) and to identify the zones within which the processes are dominant. A general mixing-zone model must therefore be a series of submodels, each of which can handle a zone that is dominated by one of the principal mixing processes. The submodels must be capable of determining the limits of their applicable zones and passing concentration values at these limits on to other submodels so that the entire mixing zone may be estimated. The following tabulation presents a summary of the steady-state physical processes that might be suitable for inclusion as submodels in a general mixing-zone model. Sources that presently seem to present the most promising empirical and analytical solutions to these submodel processes are also presented in the tabulation.

| <u>Physical Process to Be Handled by a Submodel</u> | <u>Source</u> |
|---|--|
| Momentum and/or buoyancy-dominated jets | Zeller et al. (1971) Motz and Benedict (1972) Buhler and Hauenstein (1981) Jirka et al. (1981) Wright (1984) |
| 3-dimensional dispersion in receiving water (receiving water channel must be idealized to have a trapezoidal cross section) | Prakash (1977) Fischer et al. (1979) |
| 2-dimensional vertically averaged dispersion in receiving waters (model can handle real channel cross section) | Stefan and Gulliver (1978) Paily and Sayre (1978) Gowda (1984a, b) |

It should be noted that a model for computing the fate of continuously discharged dredged material developed by Brandsma and Divoky (1976), and

modified by Johnson (1987) simulates all of the processes above within the framework of a single model. Although modifications would be needed to make the model suitable for a broad range of mixing zone conditions, it should be considered in future developmental efforts to provide a general mixing zone model.

Summary

Estimation of mixing zones is a necessary step in evaluating discharges from confined dredged material disposal areas whenever contaminant concentrations at the point of discharge are above water quality standards for the receiving water. A simplistic two-dimensional calculation procedure may be used to estimate the mixing-zone size if certain assumptions regarding geometry and flow conditions within the receiving water body are met. For more complex conditions, a numerical model solution would be required. Although no model is readily available that meets all requirements, appropriate solution techniques have been identified.

References

Buhler, J., and Hauenstein, W. 1981. "Axismetric Jets in a Crossflow," 19th Congress of the International Association of Hydraulic Research, New Delhi, India, February 1-8, 1981.

Brandsma, M. G. and Divoky, D. J. 1976. "Development of Models for Prediction of Short-term Fate of Dredged Material Discharged in the Estuarine Environment," Contract Report D-76-5, DACW39-74-C-0075, Tetra Tech, Inc., US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Earhardt, G. H. 1984. "Monitoring Total Suspended Solids Using Nephelometry," *Environmental Management*, Vol 8, No 1, pp 81-86.

Environmental Effects Laboratory. 1976. "Ecological Evaluation of Proposed Discharge of Dredged and Fill Material into Navigable Waters," Miscellaneous Paper D-76-17, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Environmental Protection Agency. 1980a. "Guidelines for Specification of Disposal Sites for Dredged or Fill Material," *Federal Register*, Vol 45, No 249, 24 December 1980, pp 85336-85357.

Environmental Protection Agency. 1980b. "Testing Requirements for the Specification of Disposal Sites for Dredged or Fill Material," *Federal Register*, Vol 45, No 249, 24 December 1980, pp 85360-85367.

Fischer, H. R., et al. 1979. *Mixing in Inland and Coastal Waters*, Academic Press, Inc., New York, NY.

Jirka, G. H., et al. 1981. "Buoyant Surface Jets," *Journal of the Hydraulics Division*, American Society of Civil Engineers, Vol 107, No HY11, pp 1467-1487.

Gowda, T. P. H. 1984a. "Critical Point Method for Mixing Zones in Rivers," *Journal of Environmental Engineering*, Vol 110, No 1, pp 244-262.

Gowda, T. P. H. 1984b. "Water Quality Prediction in Mixing Zones of Rivers," *Journal of Environmental Engineering*, Vol 110, No 4, pp 751-769.

Johnson, B. H. In review. "User's Guide for Models of Dredged Material Disposal in Open Water," Technical Report in review, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

MacIntyre, D. F. In review. "Development of Procedures for Estimating Mixing Zones from Confined Dredged Material Disposal Areas," Technical Report in review, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Motz, L. H., and Benedict, B. A. 1972. "Surface Jet Model for Heated Discharges," *Journal of the Hydraulics Division*, American Society of Civil Engineers, Vol 98, No HY11, pp 181-199.

Paily, P. P., and Sayre, W. W. 1978. "Model for Shore-Attached Thermal Plumes in Rivers," *Journal of the Hydraulics Division*, American Society of Civil Engineers, Vol 104, No HY5, pp 709-723.

Palermo, M. R. 1986. "Interim Guidance for Predicting the Quality of Effluent Discharged from Confined Dredged Material Disposal Areas," Miscellaneous Paper D-86-1 and *Environmental Effects of Dredging*, Technical Notes EEDP-04-1 through 4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Prakash, A. 1977. "Convective-Dispersion in Perennial Streams," *Journal of the Environmental Engineering Division*, American Society of Civil Engineers, Vol 103, No EE2, pp 321-340.

Saenz, M., and Parker, F. L. 1984. "Evaluation of Mathematical Models for Use in Predicting Dispersion of Suspended Solids from Dredged Material Containment Area Effluents," report prepared by Vanderbilt University for the US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Stefan, H., and Gulliver, J. S. 1978. "Effluent Mixing Zone in a Shallow River," *Journal of the Environmental Engineering Division*, American Society of Civil Engineers, Vol 104, No EE2, pp 199-213.

Wright, S. J. 1984. "Buoyant Jets in Density-Stratified Crossflow," *Journal of Hydraulic Engineering*, American Society of Civil Engineers, Vol 110, No 5, pp 643-656.

Zeller, R. W., et al. 1971. "Heated Surface Jets in Steady Crosscurrent," *Journal of the Hydraulics Division*, American Society of Civil Engineers, Vol 97, No HY9, pp 1403-1426.